REVIEW ARTICLE

Hydrogels for Textile Applications - Review

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ABSTRACT: Hydrogels are widely used in biomedical area of research. Hydrogels are usually used in fabrication of contact lenses, hygiene products, biosensors, wound dressings, and tissue engineering applications. The polymer 2-hydroxyethyl methacrylate (HEMA) based hydrogel synthesis and their use in textiles industry was also reviewed. Poly-Hema is a soft, flexible, water absorbing plastic used in making soft contact lenses. HEMA is a clear liquid compound obtained by reacting methacrylic acid with ethylene oxide or propylene oxide. HEMA and polymer hydrogel filler are used for soft tissue reconstruction by facile polymerization. The synthesis of random copolymer including HEMA through free radical polymerization is also reviewed. Polymeric fillers are widely used as an alternative for breast reconstruction materials. This review focuses on recent advancements in several types of biomedical hydrogels including conductive hydrogels, injectable, responsive, nanocomposite hydrogels, etc. Thermo responsive hydrogels use temperature as external stimulus to show sol-gel transition and they can form hydrogel around the body temperature. Textile based transdermal therapy is currently being applied using drug loaded thermoresponsive hydrogel. Hydrogels made by natural and synthetic polymers for textile based transdermal treatments are mentioned.

KEYWORDS: poly hema, thermoresponsive hydrogel, polymeric fillers, transdermal therapy, smart textiles, tissue engineering,

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INTRODUCTION

Hydrogels is a network of cross-linked polymer chains that are hydrophilic, sometimes found as colloidal gel in which water is in dispersion medium. A three-dimensional solid from the hydrophilic polymer chains being held together by cross-links. Hydrogel exhibits a degree of flexibility very identical to natural tissue because of their significant water content. The hydrophilicity of the network is due to the presence of hydrophillic groups such as -NH2, -COOH, -CONH2, and -CONH. Hydrogel undergo significant volume phase transition or sol-gel phase transition in response to certain physical and chemical stimuli [1]. Hydrogels are made up of hydrophillic components are porous 3-D interpenetrating polymeric network containing large amount of water with losing their structure at physiological temperature and pH [2,3]. They have the ability to hold water and resistance to dissolution as it contains hydrophillic functional groups and cross-linking between the polymeric chain networks respectively. High affinity of water gives hydrogels the physical properties corresponding to living tissue [4].

Hydrogels can be classified as natural, synthetic, and hybrid depending on nature of polymers. Natural polymer based hydrogels has properties such as biodegradability, biocompatibility, no-toxicity and support cellular activities [5]. Synthetic polymer based hydrogel have defined structures and some interesting features such as water content, mechanical stability, soft tissue similarities, and proved support for axonal regeneration. They are non-degradable.[6]. Some common types of hydrogels are pH-sensitive hydrogels, temperature sensitive hydrogels, electrosensitive hydrogels, light-responsive hydrogels, etc. Hydrogels are used in many fields such as drug delivery system, tissue engineering, surface coating, bone healing, developing contact lenses and several diagnostics tool [7-9]. Now-a-days HEMA based hydrogel is produced and used in textile applications.

Recently conventional invasive breast reconstruction methods are being replaced by non-invasive breast reconstruction practices because polydimethylsiloxane can cause several problems such as implant rupture, infection, hematoma, and foreign body reaction [10]. In these procedures, fillers are used as a substitute for the implant [11]. Soft tissue fillers such as hyaluronic acid, collagen, acrylamide, polymethylmethacrylate are used for cosmetic surgeries [12]. Material based fillers have rapid absorption and their structures have relatively low stability [13]. In this study, 2 hydroxyethyl methacrylate (HEMA) and acrylamide (Am)

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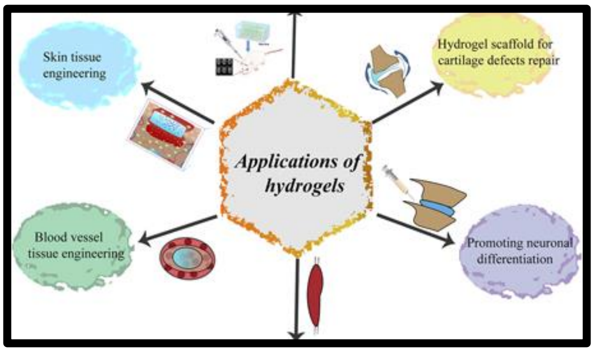
copolymer Poly (HEMA-Am) hydrogel were synthesized by redox polymerization as new synthetic filler. Poly (HEMA-Am) hydrogel as a synthetic based filling material is capable of providing a stable structure and bio compatibility that can be used as injectable filler for breast reconstruction [14-16].



Temperature responsive polymers are widely used in wearable electronics, drug delivery system, temperature based separation, and smart Textiles [17].Thermoresponsive polymers maintain hydrophobic and hydrophilic balance in their structure and have biomedical applications especially in drug delivery for cancer therapy, transdermal drug therapy used in smart textiles, tissue repair and bone regeneration [18,19]. Natural polymers such as xyloglucan, dextran, elastin and elastin like polypeptide/ oligopeptide and synthetic polymers such as polyoxazoline, biodegradable polyester copolymers can form thermoresponsive hydrogels [20]. Some of the thermoresponsive hydrogels of natural and synthetic polymers are given below:

Natural polymers

Chitosan*:* It is a deacetylated product of chitin is used in wide range of biomedical applications [21]. Chitosan is soluble in dilute aqueous acids. Chitosan is a natural cationic biopolymer made of glucosamine units, can form hydrogels as the polymer is hydrophillic, biocompatible, etc. Chitosan based hydrogels are used in textile industry and have biomedical applications such as atopic dermatitis [22]. Textile therapy using Micro encapsulation technology was developed for the treatment of Atopic dermatitis by chitosan based hydrogel. [23]. The Chinese herbal medicines were loaded into chitosan and sodium alginate composite micro encapsules using emulsion chemical cross linking method and a pad-dry cure approach was then employed to coat the micro-capsules on the surface of cotton fabrics [24]. Hydrogel film composed of chitosan and honey was developed for textile applications, as it is capable of water vapour transmission and water absorption [25].This film fulfilled all the requirements of the wound dressing such as strength, elongation, thickness, degradation, etc. Hydrogels with three components, poly (vinyl alcohol) (PVA), carboxymethylate chitosan (CM-chitosan) and honey have been prepared by using radiation method and radiation followed by freeze-thawing cycles technique (combinational method). This method improves mechanical strength of hydrogels and decreases swelling of hydrogels also it protects from bacterial infection. In the formulation of gels, presence of honey is important as it has led to higher tissue regeneration [26]. Development of chitosan composite hydrogel based textile scaffolds for tissue engineering and the scaffolds were prepared by a freeze drying technique using woven PES fabric with well defined macro porosity coated with a biodegradable chitosan-collagen membrane [27, 28]. This provided a 3-D structure for cell attachment and growth. Chitosan based hydrogels are applicable in removal of heavy metal ions due to the presence of multiple amino and hydroxyl groups in their structure. Chemical modification of these functional groups can improve absorption capacity physiochemical properties of chitosan [29,30].

Gelatin/collagen

Collagen is the most abundant protein in your body while gelatin is a cooked/degraded form of collagen. Gelatin has thermoresponsive properties and is commercially produced from by-products of the meat and leather industries. Gelatin is biodegradable, bio-compatible, non-toxic, high carbon content, abundant, low price and can accept easy modifications on the amino acid level [31,32].Hydrogels made of an interpenetrating network of gelatin, sodium alginate and CNC's were applied for cartilage applications [33]. Gelatinmethacryloyl (GelMA) hydrogels were used for biomedical applications such as tissue engineering, drug and gene delivery, bio-sensing, due to their suitable biological properties and tunable physical characteristics [34,35]. An injectable thermoresponsive hydrogel system was formed from blends of chitosan and gelatin and their solutions can form gels very quickly at the body temperature. It was biodegradable, biocompatible, adhesive to human tissue and used for the delivery of protein drug [36]. The chitosan-gelatin micro encapsules loaded with patchouli oil was grafted onto cotton fabric using 2-D resin as cross-linking reagent [37,38]. Chitosan gelatin micro encapsules has applications in many fields such as antibacterial mask, bacteriostatic sheet and healthcare clothes [39].Hydrogel layer was

made of alginate/ methacrylated gelatin or thermally cross-linkable hydrogels such as collagen and gelatin. This new and innovative textile technology has been utilized for the bio fabrication of fibrous scaffolds for various tissue engineering applications [40,41].

Synthetic polymers

Poly(N-isopropylacrylamide)

Thermoresponsive based on hydrogels from P-NIPAm, its copolymers and materials are useful for developing sensors and actuators, operations in biotechnology, processing of agricultural products, etc [42].Thermoresponsive hydrogel of NIPA-Am copolymers with acrylic acid (AA) p(NIPA Am-co AA) was applied as a cell and drug delivery vehicle [43]. P(NIPAAm) based thermoresponsive hydrogel has various textile applications. P(NIPAAm) coated cotton fabric showed an extraordinary capacity of collecting water from humid air. A cotton fabric coated with pNIPAAm via atom transfer radical polymerization exhibited an excellent transition from super hydrophilicity to hydrophobicity with changing temperature for developing thermoresponsive smart textiles [44,45]. The nano-hydrogel of chitosan and NIPAAm was made of surfactant free emulsion polymerization and coated on to cotton using 4-butane tetra carboxylic acid (BTCA) as environment friendly cross-linking agent. This enhanced the water retention capacity of cotton fabric [46]. These hydrogels were applied to textiles to improve their water retention capacity and enhance their capacity for collecting water from air.

Pluronics or Poloxamers: Poloxamers are non-ionic tri block copolymers composed of a central hydrophobic chain of polyoxypropylene flanked by two hydrophillic chains of polyoxyethylene and they are capable of slowing their no responsive behaviour in aqueous solutions at physiological temperature and pH [47,48]. The gelling process of pluronics hydrogels is comprised of two steps:

Micellization Process, Gelation Process

Micellization process is formation of spherical micelles and gelation process in which assembling of spherical micelles occurs to form gel. Pluronic F127 has various biomedical applications such as tissue engineering and burn wound covering [49-51]. For textile applications, PF127 based hydrogels are applied for transdermal drug delivery [52]. Herbal medicine loadedPF127 based thermoresponsive hydrogel is capable of moisturizing the skin and relieving the symptoms of atopic dermatitis. Nevertheless, more modifications are required to improve the drug loading capacity of PF127 based hydrogel. Transdermal studies showed that permeability of the drug through the skin has enhanced with the addition of CMC's in hydrogel formulation [53-55].

The halogenated products available in the market like brominated flame retardant, chlorinated flame retardant arenon eco-friendly and are a major health concern as well as unsafe for human life. These flame retardants emit toxic gases such as hydrogen bromide (HBr) and hydrogen chloride (HCl) during combustion which is harmful to respiratory system. Hence, halogen-free flame retardants have been increasingly sought after due to public interests concerning health, safety and environmental aspects. Hence the need for non-halogenated products has arisen. The method of synthesis to obtain a flame retardant by using a hydrogel like HEMA by reacting HEMA (2-hydroxyethyl methacrylate) with organophosphate was carried out. After several experimentations successful synthesis of product was obtained. The results showed that the addition of a photo initiator increases the conversion rates of polymerization of the FR.

This product was then applied on jute fabric by the pad dry cure technique. To optimize the curing concentration, the curing time and temperature, the jute fabric was treated with 10%, 20%, 30% concentration of product 1 at temperature 110^{0}C, 120^{0}C, 130^{0}C and curing time 2 min, 3 min, 4 min was carried out, to optimize the finishing conditions. It is found that for curing temperature of 120^{0}C and 4 minutes curing time product has maximum add on with minimum char length. LOI of this sample was found to be 35which is more than other treated fabrics. Thus successful flame retardant finish was obtained using a hydrogel like HEMA [56,57]. Thus the application of hydrogels can be summarized as given in the following Table I.

CONCLUSION

Textile-based thermoresponsive hydrogel system exhibits the functions of drug control release and moisture and exudate management. The sweat, blood and other body fluids can be effectively drained out of the skin in a unidirectional manner (from inside to outside), which shows great significance in keeping the topical skin area clean, breathable and comfortable for long term treatment, e.g., application as a wound bed in a moist environment. For application based on particular tissues or organs, much research remains to develop hydrogels capable of functioning as

replacements for real tissue. Future studies into bio-medical hydrogels will be needed to address the following:

Table I Natural and synthetic polymers used as hydrogels for drug delivery, Textile Application, and Tissue engineering.

Polymer	Chemical nature	Type of stimuli-responsiveness	Biomedical applications
Chitosan	Natural (polysaccharide)	Thermoresponsive pH responsive	Drug delivery, tissue engineering, textile Application.[21]
Cellulose	Natural (polysaccharide)	Thermoresponsive pH responsive.	Drug delivery, tissue engineering, textile Application.
Albumin	Natural (polypeptide)	Thermoresponsive pH responsive	Drug delivery, tissue engineering, textile Application.
Gelatin	Natural (polypeptide)	Thermoresponsive pH responsive	Drug delivery, tissue engineering, textile Application [34].
PF127	Synthetic	Thermoresponsive in situ-gel formation	Drug delivery, textile based transdermal therapy. [49-51]
pNiPAAm	Synthetic	Thermoresponsive in situ-gel formation	Drug delivery, Textile Application [43].
PEO	Synthetic	pH responsive (neutral)	Drug delivery, Textile Application.
PAA	Synthetic	pH responsive (anionic)	Drug delivery, Textile Application.
PDMAEMA/ PDEAEMA	Synthetic	pH responsive (cationic)	Drug delivery, Textile Application [58]

- ✓ Swelling rate of hydrogels should be controlled while improving their mechanical properties, meeting size requirements of tissues and organs.
- ✓ Their bio-compatible should be enhanced to achieve stimulation of extracellular matrix structure and functions.
- ✓ Degradation rate of hydrogels should be controllable, conforming to tissue specific much properties and regeneration needs.
- ✓ Reduction of the effect on the mechanical properties of textile materials.
- ✓ Health and environmental effects of hydrogel-based finishes, by addressing problems of toxic side effects, as well as the biodegradability of disposed functionalized textiles and the bioaccumulation of hydrogel compounds.
- ✓ Optimization of synthesis methods to minimize Production costs.

Hydrogels should be combined with other materials to achieve the complex structural and functional components necessary to act as replacement for specific organs. Poly (HEMA-Am) hydrogel filler is a promising filler material with stable structure and good bio-compatibility that can be used as permanent injectable filler for breast reconstruction. Various thermoresponsive hydrogels which can use moderate temperature change as a trigger for sol-gel transition and at body temperature injectable thermoresponsive polymers can form gel from their aqueous solution and their textile applications were studied.

REFERENCES

[1] Morteza Bahram, NaimehMohseni, Mehdi Moghtader, (August 24th 2016). An Introduction to Hydrogels and Some Recent Applications, Emerging Concepts in Analysis and Applications of Hydrogels, Sutapa Biswas Majee, IntechOpen.

[2] Hoffman, A. S., 2002. Hydrogels for biomedical applications, advanced drug delivery reviews, 54(1), 3–12.

[3] Ferreira, N.N.; Ferreira, L.M.B., Cardoso, V.M.O., Boni, F.I., Souza, A.L.R.,Gremião, M.P.D., 2018. Recent advances in smart hydrogels for biomedical applications, From self-assembly to functional approaches, Eur. Polym. J. , 99, 117–133.

[4] Chirani, Naziha, Yahia, L'Hocine&Gritsch, Lukas., Motta, Federico Chirani, Soumia, Farè, Silvia, 2015. History and Applications of Hydrogels, Journal of Biomedical Sciences, Vol. 4, 13-23.

[5] M.Khansari, Maziyar, 2017, Classification of Hydrogels Based on Their Source: A Review and Application in Stem Cell Regulation, The Minerals, Metals & Materials Society.

[6] Wang, F., Li, Z., Khan, M., Tamama, K., Kuppusamy, P., Wagner, W. R., Sen, C. K., & Guan, J., 2010, Injectable, rapid gelling and highly flexible hydrogel composites as growth factor and cell carriers, Actabiomaterialia, 6(6), 1978–1991.

[7] Lee, K. Y., Mooney, D. J., 2001. Hydrogels for tissue engineering, Chemical reviews, 101(7), 1869–1879.

[8] Enrica CalÃ, Vitaliy, V., Khutoryanskiy, 2015. Biomedical applications of hydrogels: A review of patents and commercial products, European Polymer Journal, 65, 252-267.

[9] El-Sherbiny, I. M., Yacoub, M. H., 2013. Hydrogel scaffolds for tissue engineering: Progress and challenges, Global cardiology science& practice, 2013(3),316–342.

[10] Bitar G., 2009. Breast Augmentation: Axillary Approach. In: Shiffman M. (eds) Breast Augmentation. Springer, Berlin, Heidelberg, pp- 231-240.

[11] Roh, T.S., 2016, Letter: Position Statement of Korean Academic Society of Aesthetic and Reconstructive Breast Surgery: Concerning the Use of Aqua filling for Breast Augmentation. Arch. Aesthetic Plast. Surg, 22, 45–46.

[12] Broder, K.W., Cohen, S.R., 2006. An overview of permanent and semipermanent fillers. Plast. Reconstr.Surg, 118, 7S–14S.

[13] Bergeret-Galley C., 2004. Comparison of reabsorbable soft tissue fillers. Aesthetic surgery journal, 24(1), 33–46.

[14] Zhao, P., Zhao, W., Zhang, K., Lin, H. and Zhang, X. 2019, Polymeric injectable fillers for cosmetology: Current status, future trends, and regulatory perspectives. J Appl.Polym.Sci, 137, 48515.

[15] Dalto PD., Shoichet MS., 2001 Creating porous tubes by centrifugal forces for soft tissue application, Biomaterials;22(19) 2661-2669.

[16] Sue, G. R., Seither, J. G., Nguyen, D. H., (2019). Use of hyaluronic acid filler for enhancement of nipple projection following breast reconstruction: An easy and effective technique. JPRAS open, 23, 19–25.

[17] Lei, Z., Wang, Q., Wu, P., 2017, A multifunctional skin-like sensor based on a 3D printed thermo-responsive hydrogel. Mater. Horiz., 4, 694–700.

[18] Ahmad, H., Sultana, M.,Alam, M., Rahman, M., Tauer, K., Gafur, M., Sharafat, M., 2016. Evaluating a simple blending approach to prepare magnetic and stimuli-responsive composite hydrogel particles for application in biomedical field, Express Polym. Lett., 10, 664–678.

[19] Khan, R., Mahendhiran, B., Aroulmoji V., 2013. Chemistry of Hyaluronic acid and its significance as a biocompatible drug delivery vehicle: A Review, International Journal of Pharmaceutical Sciences and Research 4: 10. 3699-3710.

[20] Klouda, L., Mikos, A. G., 2008. Thermoresponsive hydrogels in biomedical applications. European journal of pharmaceutics and biopharmaceutics : official journal of Arbeitsgemeinschaft fur Pharmazeutische Verfahrenstechnike.V, 68(1), 34–45.

[21] Bhattarai, N., Gunn, J., Zhang, M., 2010. Chitosan-based hydrogels for controlled, localized drug delivery. Adv. Drug Delivery Rev , 62, 83– 99.

[22] Wang, W., Hui PCL., Kan C-W., 2017. Functionalized Textile Based Therapy for the Treatment of Atopic Dermatitis. Coatings, 7(6):82.

[23] Hui, P.C.-L., Wang, W.-Y.,Kan, C.-W., Ng, F.S.-F., Zhou, C.-E., Wat, E., Zhang, V.X., Chan, C.-L., Lau, C.B.-S., Leung, P.-C., 2013, Preparation and characterization of chitosan/sodium alginate (CSA) microcapsule containing Cortex Moutan. Colloid Surf. A , 434, 95–101.

[24] Hui, P. C., Wang, W. Y., Kan, C. W., Ng, F. S., Wat, E., Zhang, V. X., Chan, C. L., Lau, C. B., & Leung, P. C., 2013. Microencapsulation of Traditional Chinese Herbs-PentaHerbs extracts and potential application in healthcare textiles, Colloids and surfaces. B, Biointerfaces, 111, 156–161.

[25] Sasikala, L., Durai, B., Rathinamoorthy, R., 2013. Manuka honey loaded chitosan hydrogel films for wound dressing applications, Int. J. PharmTech. Res. 5, 1774–1785.

[26] Afshari, M.J., Sheikh, N., Afarideh, H., 2015. PVA/CM-chitosan/honey hydrogels prepared by using the combined technique of irradiation followed by freeze-thawing,

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Radiation Physics and Chemistry;113; 28-35.

[27] Arakawa, C., Ng, R., Tan, S., Kim, S., Wu, B., & Lee, M., 2017. Photopolymerizable chitosan-collagen hydrogels for bone tissue engineering. Journal of tissue engineering and regenerative medicine, 11(1), 164–174.

[28] Makarand V. Risbud, ErdalKaramuk, Viola Schlosser, Joerg Mayer, 2003. Hydrogel-coated textile scaffolds as candidate in liver tissue engineering: II. Evaluation of spheroid formation and viability of hepatocytes, Journal of Biomaterials Science, Polymer Edition, 14:7, 719-731.

[29] Ramesh, A., Hasegawa, H., Sugimoto, W., Maki, T., Ueda, K., 2018. Adsorption of gold(III), platinum(IV) and palladium(II) onto glycine modified crosslinked chitosan resin. Bioresour Technol. 99(9):3801-3809.

[30] Kandile Nadia G., Nasr Abir S.,2009., Environment friendly modified chitosan hydrogels as a matrix for adsorption of metal ions, synthesis and characterization Carbohydrate polymers ;78(4) 753-759.

[31] Jaipan, P., Nguyen, A., Narayan, RJ., 2017. Gelatin-based hydrogels for biomedical applications.MRSCommunications.;7(3):416-426.

[32] Seblewongel Petros, Tamrat Tesfaye, Million Ayele,2020. A Review on Gelatin Based Hydrogels for Medical Textile Applications", Journal of Engineering, ID 8866582

[33] Naseri, N., Deepa, B., Mathew, A. P., Oksman, K., Girandon, L.,2016. Nanocellulose-Based Interpenetrating Polymer Network (IPN) Hydrogels for Cartilage Applications, Biomacromolecules, 17(11), 3714–3723.

[34] Yue, K., Trujillo-de Santiago, G., Alvarez, M. M., Tamayol, A., Annabi, N., Khademhosseini, A., 2015. Synthesis, properties, and biomedical applications of gelatinmethacryloyl (GelMA) hydrogels, Biomaterials, 73, 254–271.

[35] Xiao, S., Zhao, T., Wang, J., Wang, C., Du, J., Ying, L., Lin, J., Zhang, C., Hu, W., Wang, L., Xu, K., 2019. Gelatin Methacrylate (GelMA)-Based Hydrogels for Cell Transplantation: an Effective Strategy for Tissue Engineering. Stem cell reviews and reports, 15(5), 664–679.

[36] Chang, Y., Xiao, L. And Tang, Q., (2009), Preparation and characterization of a novel thermosensitive hydrogel based on chitosan and gelatin blends. J. Appl. Polym. Sci., 113: 400-407.

[37] Liu, J., Liu, C., Liu, Y., Chen, M., Hu, Y., & Yang, Z., 2013. Study on the grafting of chitosan-gelatin microcapsules onto cotton fabrics and its antibacterial effect, Colloids and surfaces. B, Biointerfaces, 109, 103–108.

[38] Leong, W., Huang, G., Khan, I., Xia, W., Li, Y., Liu, Y., Li, X., Han, R., Su, Z., & Hsiao, W., (2019). Patchouli Essential Oil and Its Derived Compounds Revealed Prebiotic-Like Effects in C57BL/6J Mice, Frontiers in pharmacology, 10, 1229.

[39] Călinoiu, L-F., Ştefănescu, BE., Pop ID., Muntean, L., Vodnar DC., 2019. Chitosan Coating Applications in Probiotic Microencapsulation, Coatings, 9(3), 194.

[40] Akbari, M., Tamayol, A., Laforte, V., Annabi, N., Najafabadi, A.H.,Khademhosseini, A., Juncker, D., 2014. Composite living fibers for creating tissue constructs using textile techniques. Adv. Funct. Mater, 24, 4060–4067.

[41] Goodarzi, H., Jadidi, K., Pourmotabed, S., Sharifi, E., Aghamollaei, H., 2019. Preparation and in vitro characterization of cross-linked collagen-gelatin hydrogel using EDC/NHS for corneal tissue engineering applications, International journal of biological macromolecules, 126, 620–632.

[42] Gulyuz, U., And Okay, O., (2015), Self-Healing Poly(acrylic acid) Hydrogels: Effect of Surfactant, Macromol, Symp., 358: 232-238.

[43] Na, K., Park, J. H., Kim, S. W., Sun, B. K., Woo, D. G., Chung, H. M., Park, K. H., (2006). Delivery of dexamethasone, ascorbate, and growth factor (TGF beta-3) in thermo-reversible hydrogel constructs embedded with rabbit chondrocytes, Biomaterials, 27(35), 5951–5957.

[44] Hu, J., Meng, H., Li, G.,Ibekwe, S.I., 2012. A review of stimuli-responsive polymers for smart textile applications, Smart Mater, Struct, 21, 053001.

[45] Cheng Jiang, Qihua Wang, Tingmei Wang., 2012.ThermoresponsivePNIPAAm-modified cotton fabric surfaces that switch between super hydrophilicity and super hydrophobicity, Applied Surface Science, 258(11)., 4888-4892.

[46] Bashari, A., Hemmatinejad, N.,Pourjavadi, A.,2013. Surface modification of cotton fabric with dual-responsive B, PNIPAAm/chitosan nano hydrogel, Polym. Adv. Technol, 24, 797–806.

[47] Alexandridis, P., Hatton, T.A., 1995. Poly(ethylene oxide)-poly (propylene oxide)- poly(ethylene oxide) block copolymer surfactants in aqueous solutions and interfaces: Thermodynamics, structure, dynamics and modeling. Colloid Surf. A , 96, 1–46.

[48] Batrakova, E. V., Kabanov, A. V., (2008). Pluronic block copolymers: evolution of drug delivery concept from inert nanocarriers to biological response modifiers, Journal of controlled release: official journal of the Controlled Release Society, 130(2), 98–106.

[49] Yap, L. S., Yang, M. C., (2016). Evaluation of hydrogel composing of Pluronic F127 and carboxymethyl hexanoyl chitosan as injectable scaffold for tissue engineering applications, Colloids and surfaces. B, Biointerfaces, 146, 204–211.

[50] Schmolka I. R., (1972). Artificial skin. I. Preparation and properties of pluronic F-127 gels for treatment of burns, Journal of biomedical materials research, 6(6), 571–582.

[51] Emilia Gioffredi, Monica Boffito, Stefano Calzone, Sara Maria Giannitelli, Alberto Rainer, Marcella Trombetta, Pamela Mozetic, Valeria Chiono, 2016.Pluronic F127 Hydrogel Characterization and Biofabrication in Cellularized Constructs for Tissue Engineering Applications, Procedia CIRP, 49, 125-132.

[52] Jiang, L., Shan, A. H., Young, D. J., Li, Z., Loh, X. J., (2019). Polyester-based Biodegradable Thermogelling System as Emerging Materials for Therapeutic Applications, In X. Loh (Ed.), Biodegradable Thermogels (pp. 40–75), Royal Society of Chemistry (R S C) Publications.

[53] Higuchi, A., Aoki, N., Yamamoto, T., Gomei, Y., Egashira, S., Matsuoka, Y., Miyazaki, T., Fukushima, H., Jyujyoji, S., & Natori, S. H., (2006). Bioinert surface of pluronic-immobilized flask for preservation of hematopoietic stem cells, Biomacromolecules, 7(4), 1083–1089.

[54] Wang, W., Wat, E., Hui, P. C., Chan, B., Ng, F. S., Kan, C. W., Wang, X., Hu, H., Wong, E. C., Lau, C. B., Leung, P. C. (2016). Dual-functional transdermal drug delivery system with controllable drug loading based on thermosensitive poloxamer hydrogel for atopic dermatitis treatment, scientific reports, 6, 24112.

[55] Wang, Jerry & Hui, Patrick & Wat, Elaine & Ng, Frency& Kan, Chi-Wai & Wang, Xiaowen& Wong, Eric & Hu, Huawen& Chan, Ben & Lau, Clara & Leung, Ping-Chung, (2016). In vitro drug release and percutaneous behavior of poloxamer-based hydrogel formulation containing traditional Chinese medicine, Colloids and Surfaces B: Biointerfaces. 148, 526-532.

[56] Chanchal Kumar Kundu, Zhiwei Li, Lei Song, Yuan Hu, 2020. An overview of fire retardant treatments for synthetic textiles: From traditional approaches to recent applications, European Polymer Journal, 137, 109911.

[57] Samanta, Kartick, K.,SantanuBasak and S.K., Chattopadhyay, 2015. "Sustainable Flame-Retardant Finishing of Textiles Advancement in Technology" , in Handbook of Sustainable Apparel Production ed. Subramanian Senthilkannan Muthu., (Boca Raton: CRC Press, accessed 17 Apr 2021 , Routledge Handbooks Online.

[58] Chatterjee, S., Chi-leung, HUI P., 2019. Review of Stimuli-Responsive Polymers in Drug Delivery and Textile Application, Molecules, 24(14), 2547.